Threatened plant communities of Western Australia. 1. The ironstone communities of the Swan and Scott Coastal Plains

N Gibson[1], G Keighery[1], & B Keighery[2]

[1] CALMScience, Department of Conservation and Land Management, Wildlife Research Centre, PO Box 51 Wanneroo WA 6065.
email: *neilg@calm.wa.gov.au; gregk@calm.wa.gov.au*
[2] Department of Environmental Protection, 141 St Georges Terrace WA 6000.
email: *bronwen_keighery@environ.wa.gov.au*

Manuscript received September 1999; accepted December, 1999

Abstract

The restricted plant communities of the massive ironstones (ferricretes) of the Swan and Scott Coastal Plains are described. These communities are amongst the most threatened in Western Australia. Much of the original extent of these communities has been cleared for agriculture, the remaining areas are threatened by *Phytophthora cinnamomi*, grazing and activities associated with mineral exploration. Twenty taxa have been recorded as being endemic to or having their major distribution centred on these ironstone areas, a further three taxa may have forms restricted to this habitat. Only eight of these 20 taxa are known from secure conservation reserves. Major differences in community composition were related to geographic and edaphic factors. Species richness ranges from an average of 14 to 67.8 taxa per 100 m^2 across the nine community types described. Only five of these community types have been recorded from secure conservation reserves. Most occurrences of these plant communities occur on ironstone areas which are much younger than the Tertiary aged laterites of the nearby Darling and Blackwood Plateaus.

Keywords: threatened community, ironstone, ferricrete, endemism

Introduction

While much has been written on the massive land clearance and loss of biodiversity of the Western Australian wheatbelt (Main 1987; Saunders & Curry 1990; Hobbs & Saunders 1994) until recently little attention has been paid to similarly impacted plant communities of the Swan Coastal Plain and the Scott Coastal Plain (Gibson *et al.* 1994; Smith & Ladd 1994; Robinson & Keighery 1997). Recent work has shown that over 95% of the fertile soils of the Swan Coastal Plain have been cleared for agriculture, a figure on par with the clearance level in the wheatbelt (personal communication, AH Burbidge & J Rolfe, CALM). Of particular interest are the recently identified ironstone communities on the Swan Coastal Plain and Scott Coastal Plain that have been massively impacted by land clearance and are generally characterised by restricted endemic taxa (Anon 1990; Gibson *et al.* 1994; Smith & Ladd 1994; Robinson & Keighery 1997). These communities are winter wet shrublands that occur on skeletal soils over the massive ironstone on the coastal plains and the foot slopes of the Whicher Range. While the existence of this geomorphological unit has long been recognised (de la Hunty 1960; Baxter 1977; Tillie & Lantzke 1990; McArthur 1991) the conservation significance of the associated plant communities has not been assessed.

The term laterite has been applied to this geomorphological unit (Johnstone *et al.* 1973; Mulcahy 1973) but is avoided here because this unit do not posses the classic pallid zone clay layer over bedrock (seen typically on the nearby Darling and Blackwood Plateaus) and are believed to be currently forming (Johnstone *et al.* 1973), contrasting with the Tertiary age of most of the laterite of the adjacent Plateaus. In this paper the term ironstone is used to describe the massive ferruginous landform unit on the Swan and Scott Coastal Plains and foot slopes of the Whicher Scarp (Tille & Lantzke 1990) and the term laterite describes the common landform on the old deeply weathered uplands of the Darling and Blackwood Plateaus. The ironstones are believed to have been formed by the precipitation of iron from the ground water mainly in the zone of water table fluctuation (Baddock 1995; Tille & Lantzke 1990; Anand 1998). They may be several metres thick overlying deep sand profiles (Belford 1987; Baddock 1995). Descriptions of soil profiles on these ironstones are given by de la Hunty (1960), Tille & Lantzke (1990) and McArthur (1991). Anand (1998) has described a similar unit on the upper valley slopes of the Darling Plateau as vesicular ferricrete, which is quite different in chemical composition from the older adjacent lateritic residuum. The aim of the present paper is to describe the flora and vegetation of the coastal plain ironstones and to determine their conservation status.

Methods

Study Sites

The southern half of the Swan Coastal Plain is a narrow belt of primarily Quaternary sands stretching 400 km from the Moore River to south of Busselton. This plain is interrupted by flood plains of a number of river systems draining off the Darling Plateau. It is these fertile

plains that have been preferentially cleared for agriculture. The coastal plain is bounded by the Indian Ocean to the west and the Darling and Whicher Scarps to the east and south. Iron rich impeding layers are common at depth on most soil types on the coastal plain resulting in variety of sumplands and damplands. However, vegetation typical of skeletal soils over massive surficial ironstone is much more restricted.

These ironstones are generally found along the base of these scarps although they can extend some distance out onto the coastal plain. They are much more restricted than depicted by Mulcahy (1973) who includes the alluvial soils of the eastern side of the plain in his low level laterite unit. The only extant areas of vegetation on ironstone on the southern coastal plain are a small area (*ca* 10 ha) near Gingin some 80 km north of Perth (original extent was *ca* 20 ha, estimated from aerial photographs), and *ca* 68 ha on the southern end of the plain south of Busselton (originally *ca* 2130 ha, mapped by Tille & Lantzke 1990).

The Scott Coastal Plain, extending from Augusta east to Walpole, is a very similar land system to the Swan Coastal Plain. The ironstone areas of the Scott Coastal Plain are apparently restricted to the western end of the plain near Scott River occurring as far east as Black Point. About 360 ha of the original 1780 ha remain uncleared.

The current extent of ironstone communities was determined by the intersection of remnant vegetation on recent aerial photography with land unit mapping of Tille & Lantzke (1990) (with some minor correction). Twenty eight 10 m x10 m plots were established in the three ironstone areas (Fig 1), one on Gingin ironstones, 11 on the Busselton ironstones and 16 on the Scott ironstones. All vascular plants were recorded within each plot. While most sites were visited on at least two occasions, some sites were visited only once in late spring when herbs and grasses were easily identifiable. In addition to flora lists, information was collected on vegetation structure, slope, aspect, degree of waterlogging and vegetation condition. Sites and species (occurring at two or more sites) were classified using Bray-Curtis association measure and UPGMA fusion algorithm to define community types and species groups (Sneath & Sokal 1973). Only taxa identified to specific level were included in the analysis.

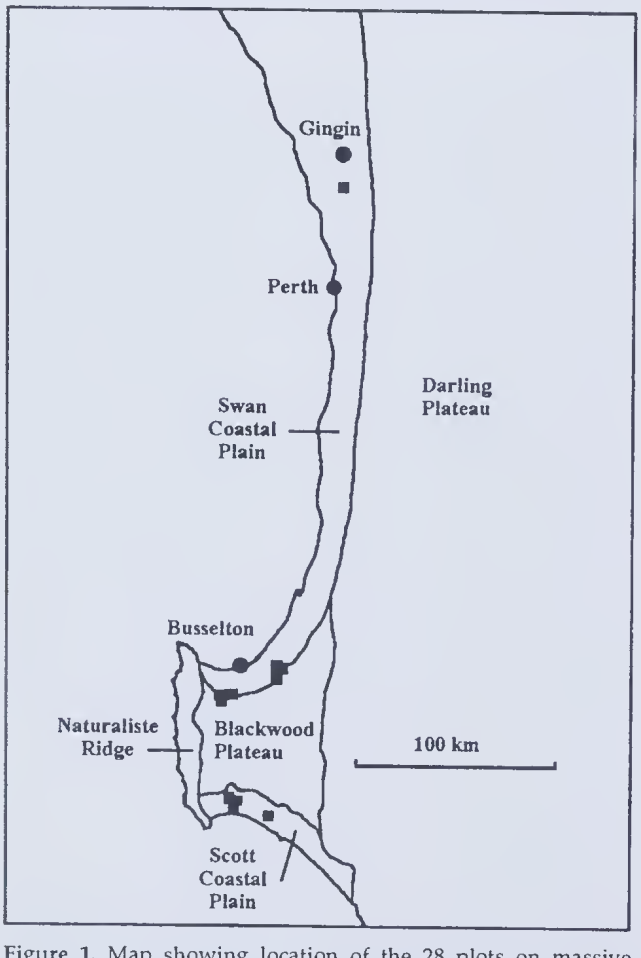

Figure 1. Map showing location of the 28 plots on massive ironstones and boundaries for the major geomorphological units. (Solid square may indicate more than one quadrat).

In addition to these 28 floristic sites, all extant ironstone patches on public lands on the Swan and Scott Coastal Plains were visited and species were noted. Complete surveys of most ironstone areas on private property have not yet been undertaken. From these data and with reference to collections held in the Western Australian Herbarium, a list of endemic taxa and taxa whose distribution is centred on the ironstone taxa was compiled. Nomenclature generally follows Green (1985) and current usage at the Western Australian Herbarium. Voucher specimens have been lodged in the Western Australian Herbarium.

Results

Flora

A total flora of some 400 taxa has been recorded from the 28 plots in the three ironstone areas, 48% of which were only recorded at a single site. Of the 400 taxa, 20 are either ironstone endemics or have their distribution centred on the ironstone areas. Eleven of these taxa are restricted to the Busselton ironstones, five occur only on the Scott ironstones and four taxa are shared between these areas (Table 1). A further three taxa *Opercularia* aff *vaginata* (BJK & NG 238), *Calothamnus* aff *quadrifidus* (BJK & NG 230), *Lepyrodia* aff *macra* (BJK & NG 1026)) also appear to be restricted to the ironstones but require further taxonomic study to fully clarify their relationships. There do not appear to be any endemic taxa on the Gingin ironstones.

Many of the ironstone endemics are recently recognised taxa and most are currently listed on the schedule of Western Australian's most threatened flora (Government Gazette, 14th July 1998). *Grevillea mccutcheonii* is, for example, restricted to a single population on a weedy road reserve and is known from only three adult plants, while *Lambertia echinata* subsp *occidentalis* is known from a single population of seven adult plants is an area badly infected by the root rot fungus *Phytophthora cinnamomi*.

Six of the 20 taxa confined to or centred on the ironstones (*Brachysema papilio*, *Darwinia* sp (GJK 12839), *Grevillea mccutcheonii*, *Lambertia echinata* subsp *occidentalis*, *Darwinia ferricola* ms, and *Melaleuca* aff *incana* (NG & ML 593) are known from only one population and these populations number from three adult plants to several thousand. *Lambertia echinata* subsp *occidentalis* occurred

Table 1

Taxa restricted or largely restricted to ironstone areas, their distribution and conservation status (Government Gazette,14th July 1998). + indicates presence, E indicates endemic on ironstone, R indicates declared rare flora.

Taxon	Swan Coastal Plain	Scott Coastal Plain
Andersonia ferricola ms	$+^{E}$	
Brachysema modesta	$+^{R}$	
Brachysema papilio	$+^{ER}$	
Chamelaucium roycei ms	$+^{R}$	
Darwinia sp (GJK 12839)	$+^{ER}$	
Dryandra squarrosa subsp *argillacea*	$+^{ER}$	
Grevillea elongata	$+^{ER}$	
Grevillea mccutcheonii	$+^{ER}$	
Hakea sp (BJK & NG 226)	+	
Lambertia echinata subsp *occidentalis*	$+^{ER}$	
Petrophile latericola ms	$+^{ER}$	
Dryandra nivea subsp *uliginosa*	$+^{ER}$	+
Calothamnus aff *crassus* (Royce 84)	$+^{E}$	+
Chordifex isomorphus	+	+
Loxocarya magna	+	+
Darwinia ferricola ms		$+^{ER}$
Grevillea aff *manglesioides* (GJK 15158)		$+^{E}$
Hakea tuberculata		+
Lambertia orbifolia		$+^{R}$
Melaleuca aff *incana* (NG & ML 593)		$+^{E}$

on somewhat deeper soils than was typical for the ironstone endemics.

Lambertia orbifolia and *Hakea tuberculata* are both known from several populations on the Scott Plain and have disjunct outlying populations in the Albany area some 250 km to the east. The Albany populations of *Hakea tuberculata* occupy a variety of habitats including winter wet flats on both ironstone and sandy substrates, while the *Lambertia orbifolia* population occurs on Tertiary laterite. *Chordifex isomorphous* has been recorded on the ironstones of both the Swan and Scott Coastal Plains as well as further disjunct populations between Mt Barker and Ravensthorpe (250 - 450 km to east) on sand and laterite substrates (Meney & Pate 1999).

Vegetation

Classification of the twenty eight floristic plots shows nine recognisable groups, here called community types (Fig 2). These community types are strongly correlated with geography and edaphic factors and to a lesser degree vegetation condition. The dendrogram shows the nine community types divide into three groups. Community types 1 to 4 occur on shallow sands and loamy sands on massive ironstones. Community types 1 to 3 occur at the base of the Whicher Scarp on the Swan Coastal Plain, while community type 4 occurs on the Scott Plain. The second group consists of community types 5 and 6 which occur on sands over massive ironstone on the Scott Plain and community type 7 which is the floristically distinct northern ironstone site. The final group is the species poor community types 8 and 9 which are restricted to the Scott Plain (Table 2).

- **Community type 1** occurs on the massive ironstones to the south of Busselton on skeletal soils. This soil layer is generally less than 1 cm deep and is often absent. This community type was the most diverse, with a mean species richness of 67.9 species per plot and was characterised by species groups B and N (Appendix 1) which are particularly rich in herb species. Herbs such as *Angianthus preissii, Aphelia nutans, Siloxerus filifolius,* and *Stylidium emarginatum* appear to be restricted to this community type.

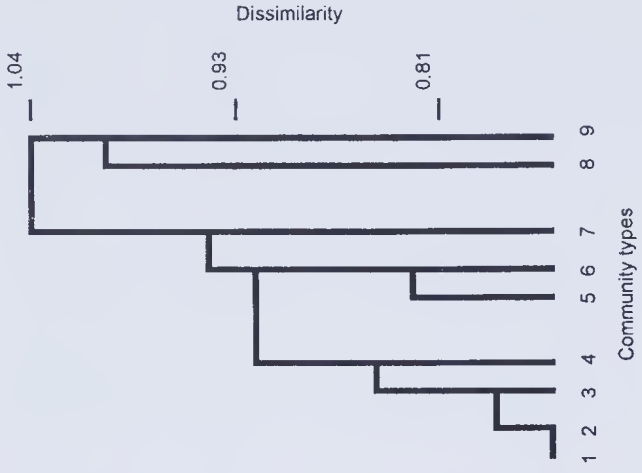

Figure 2. Dendrogram of the nine community types occurring on ironstone on Swan and Scott Coastal Plains.

Table 2

Mean species richness per plot (calculated on full species lists) and number of plots classified into each of the nine ironstone community types found on the Swan and Scott Coastal Plain ironstones.

Community type	Species richness	Number of plots
1	67.9	4
2	48.0	3
3	38.5	4
4	50.7	7
5	44.0	1
6	27.0	1
7	42.0	1
8	27.3	6
9	14.0	1

- **Community type 2** is found on the ironstones south of Busselton on slightly deeper and sandier soils. At these sites the herb layer is not as rich (e.g. lower representation of species in species groups B and N) and species such as *Lyginia barbata, Regelia ciliata* and *Chordifex serialis ms* and other species in species group L are more common.
- **Community type 3** occurs on deeper (to 10 cm) loamy sand soils on the ironstones south of Busselton. The shrub layer tends to be denser and many of the herbs seen in the two previous groups do not occur here (Appendix 1). Species groups C and G characterise this group as does the complete lack of species in species group N. Mean species richness is lower than the previous community types (Table 2).
- **Community type 4** consist of the species-rich massive ironstones of the Scott Plain. This community type shares species group B with the three Busselton groups but is differentiated by occurrence of such

species such as *Calothamnus* aff *crassus* (Royce 84), and *Velleia trinervis* in species group H, by a higher representation of species in species groups A, D, E as well as low frequency occurrence of species in species group C, K and N. This community has a higher species richness (average 50.7 species per plot) than any other community except the massive ironstones below the Whicher Scarp (type 1).

- **Community types 5 and 6** occur on the Scott Plain on more sandy substrates over massive ironstone; both are represented by only single plots. Community type 5 is species rich (Table 2) and is characterised by low representation of species in species group B and high representation of species in species group J (Appendix 1). Of the 44 taxa recorded at this site, 21 were restricted to it. Community type 6 in contrast is relatively species poor and is characterised by species group F. This site occurred close to the coast which is reflected by the presence of taxa such as *Agonis flexuosa*.
- **Community type 7** was also represented by a single site on the small area of ironstone north of Perth near Gingin. This community is characterised by a rich herb layer with carpets of Asteraceae (*Rhodanthe manglesii, Rhodanthe spicata* and *Myriocephalus helichrysoides*) a general lack of shrub layer. Of the 42 species recorded at this site 22 were not recorded from other ironstone areas.
- **Community type 8** occurs on massive ironstones on the Scott Coastal Plain. This community type is typically a dense tall shrubland with low species richness (Table 2). The closed nature of this community precludes the rich and diverse herb flora (especially in species group B) evident in the more open community type 4 which occurs on similar massive ironstones elsewhere on the Scott Plain. Taxa in species group H were most typical of this community type and contained the only sites where the ironstone endemic *Grevillea* aff *manglesioides* (GJK 15158) and *Boronia anceps* were recorded.
- **Community type 9** is represented by a single plot in a deep winter wet swamp dominated by the ironstone endemic *Melaleuca* aff *incana* (NG & ML 593). The long period of inundation well into the summer appears to restrict species richness in this community type, the only species group well represented is species group D and five species typical of winter wet swamps only occurred in this site (*Hakea linearis, Baumea juncea, Meeboldina scariosa* ms, *Meeboldina tephrina* ms, and *Platychorda applanata*). While all the ironstone communities have saturated soils during the winter and spring, only this community type is flooded to a depth of 30-50 cm for a period of several months each year.

Discussion

The high regional conservation values of the ironstone communities have been previously recognised (Anon 1990; Gibson *et al.* 1994; Smith & Ladd 1994; Robinson & Keighery 1997). More detailed work has shown that the Gingin, Busselton and Scott ironstone communities are floristically distinct and within those geographic areas further differentiation is possible which appears to be correlated with edaphic factors (particularly soil depth and clay content) as well as period of inundation. On the Scott Plain time since fire also appears to be significant since the dense shrublands of community type 8 appear to primarily differentiated from community type 4 by low occurrence of annual species.

Smith & Ladd's (1994) *Pericalymma ellipticum - Chamelaucium roycei - Grevillea diversifolia* association broadly covers the Busselton ironstones. They record only 48 species from five plots in their B2 group (mean richness 9.6 taxa per plot). This seriously underestimates the floristic diversity of this vegetation type. Our data records 236 taxa from 11 plots in this area (mean richness 21.5 taxa per plot), and average richness of the ironstone communities as a whole ranged from 14 to 67.9 taxa per plot with the richer community types being comparable with many upland heath communities. A significant component of this richness is the sequential germination and flowering of suites of annuals and geophytes (Appendix 1). This same pattern is seen in many of the clay-based wetlands on the coastal plain where high richness levels result from sequential groups of annuals that flower as the wetlands dry (personal communication, BJ Keighery & M Trudgen, DEP).

The ironstone vegetation types are a significant repository of biodiversity both in terms of high β-diversity and as a habitat for 20 restricted taxa. Of those 20 taxa 14 appear to be endemic to the ironstone substrate, while 12 are considered so seriously threatened as to be gazetted as Declared Rare Flora under the Wildlife Conservation Act 1950. The listing on this schedule is the strongest legislative protection that can be afforded to flora in Western Australia and requires Ministerial permission for any activity that may impact on these species in any way. A further seven taxa are presently being considered for gazettal (pers comm, K Atkins, CALM).

Many of these 20 taxa are still awaiting formal description or have only recently been described, indicating the incomplete state of knowledge of the flora of Western Australia even on the coastal plain within 200 km of the major population centre. Only eight of the 20 restricted taxa and five of the nine described community types are currently known from secure conservation reserves (National Parks or Nature Reserves).

The Gingin ironstone was always quite limited in area and the recent acquisition of the remaining block has conserved an estimated 50% of its original extent (Table 3). The Busselton ironstones have been the most heavily cleared for agriculture with only 3% of the original area remaining. The remnants are small and scattered and threatened by *Phytophthora cinnamomi* infection, inappropriate burning regimes and activities associated with mineral sands exploration and mining. One small remnant of *ca* 12 ha has recently been acquired as a conservation reserve while the acquisition of a second block of similar size is likely. While there are considerable areas of the Scott Plain's ironstone remaining as bushland most occurs on private property and very little occurs in secure conservation reserve (Table 3). Robinson & Keighery (1997) highlighted the importance of the recreation reserve immediately north of Scott River National Park for the conservation of the Scott Plain

Table 3

Estimates of original area, remaining uncleared area and percentage of the original in secure conservation reserve.

Area	Original area (ha)	Remaining uncleared area (ha)	%uncleared	% of original area reserved
Gingin	20	10	50	50
Busselton	2130	68	3	0.6
Scott Plain	1780	360	20	0.6

ironstone communities. Only unfavourable economic conditions of the early 1960s prevented a major iron ore mine being developed on the Scott Plains (see references in Baddock 1995).

Most of the areas of ironstone on the Swan and Scott Coastal Plains are clearly of Quaternary age (Tillie & Lantzke 1990; McArthur 1991; Baddock 1995) with the possible exception of ironstone deposits in Ironstone Gully near the base of the Whicher Range. Tille & Lantzke (1990) consider these of Quaternary age, while earlier mapping of nearby sections of the lower foot slopes of the Whicher Range indicate a Tertiary age (Belford 1987). This young age seems at variance with high level of endemism (13 taxa) seen on this substrate as well as the 50 km disjunction in distribution of several of the endemics between the Swan and Scott coastal plains (*Dryandra nivea* subsp *uliginosa*, *Calothamnus* aff *crassus*, *Chordifex isomorphus*, *Loxocarya magna*) and the 250 km disjunction of *Chordifex isomorphus*, *Hakea tuberculata* and *Lambertia orbifolia* between the Scott Plain and similar habitat in the Albany area. The absence of *Hakea tuberculata* between Scott River and Albany appears to relate to the lack of any ironstone formation in the intervening area. However, the reason for the absence of *Chordifex isomorphus*, *Lambertia orbifolia* and the endemics in seasonally wet lateritic areas on the Blackwood Plateau is not clear, but may be related to differences in chemical composition of the iron rich substrates (Anand 1998).

The evolution of the endemic flora of the ironstones may involve recent speciation events on the coastal plains after their deposition in the late Pleistocene, or much older speciation events from more widespread ancestral taxa with subsequent migration onto the ironstones of the coastal plain presumably in response to climatic change. Bousfield & James (1976) reported distinctive chromosome races for population of *Dampiera linearis* growing on the ironstones at the base of the Whicher Range compared with the diploid of the Blackwood Plateau and the tetraploid of the coastal plain but offer no suggestion of how old these chromosome races may be.

Given the present day distribution of the closest relatives of the ironstone endemics follow no consistent pattern, it is likely that the endemic species have a long evolutionary history. Four of the endemics are parapatric with their closest sister taxon, while 10 are allopatric, but separated by varying distances (one < 10 km, two between 10-50 km, one between of 50-100 km and four by more than 200 km). One endemic *Darwinia ferricola* ms has no close relative.

Of the 20 taxa whose distribution is centred on the ironstones, detailed phylogenetic and phylogeographic studies have only been undertaken for *Lambertia orbifolia* (Coates & Hamley 1999; Byrne *et al.* 1999). These studies, based on allozyme mating system, and chloroplast and nuclear rDNA analyses, indicate that a separation of the Scott Plain and Albany populations has occurred over an extended period of time in the evolutionary history of this species. Both these studies consider that genetic differentiation between these populations is such that the they should be recognised as separate conservation units.

If the phylogenetic pattern seen in *Lambertia orbifolia* is typical of the ironstone endemics then the local patterns of distribution now seen represent very recent migration onto the coastal plain of lineages with long and complex evolutionary histories.

Acknowledgments: M Lyons assisted with the field work, B Lepschi with determinations of *Melaleuca* and *Hakea* species, and V English supplied the remnant vegetation layer used on the Scott Plain to determine the area statement.

References

Anand RR 1998 Distribution, classification and evolution of ferruginous materials over greenstone on the Yilgarn Craton - implications for mineral exploration. In: The state of the regolith. Proceedings of the 2nd Australian conference on landscape evolution and mineral exploration (ed RA Eggleton). Geological Society of Australia Special Publication 20:175-193.

Anon 1990 Flora and vegetation. In: Heavy Mineral Mine - Beenup. Environmental Review and Management Program (ed Lewis Environmental Consultants). BHP-Utah Minerals International, Perth. Appendix VII:1-72.

Baddock LJ 1995 Geology and Hydrology of the Scott Coastal Plain, Perth Basin. Record 1995/7. Geological Survey of Western Australia, Perth.

Baxter JL 1977 Heavy mineral sand deposits of Western Australia. Bulletin 10. Geological Survey of Western Australia Mineral Resources, Perth.

Belford SM 1987 Capel Sheet 2030 IV, Environmental Geology Series, Geological Survey of Western Australia, Perth.

Bousfield LR & James SH (1976) The behaviour and possible cytoevolutionary significance of B chromosomes in *Dampiera linearis* (Angiospermae: Goodeniaceae). Chromosoma 55:309-323.

Byrne M, MacDonald B & Coates D (1999) Divergence in the chloroplast genome and nuclear rDNA of the rare Western Australian plant *Lambertia orbifolia* Gardner (Proteaceae). Molecular Ecology 8: in press.

Coates D & Hamley VL (1999) Genetic divergence and the mating system in the endangered and geographically restricted plant species, *Lambertia orbifolia* Gardner (Proteaceae). Heredity 83: in press.

de la Hunty LE 1960 Report on the deposit of bog-iron ore at the Scott River, South-West Land Division, Western Australia. Geological Survey of Western Australia, Perth. Annual Report 1960:21-22.

Gibson N, Keighery BJ, Keighery GJ, Burbidge AH & Lyons MN 1994 A floristic survey of the southern Swan Coastal Plain. Unpublished Report. Department of Conservation and Land Management & the Conservation Council of Western Australia.

Green JW 1985 Census of the Vascular Plants of Western Australia. Department of Agriculture, Perth.

Hobbs RJ & Saunders DA 1994 Effects of landscape fragmentation in agricultural areas. In: Conservation Biology

in Australia and Oceania (eds C Moritz & J Kikkawa). Surrey Beatty & Sons, Chipping Norton, 77-95.

Johnstone MH, Lowry DC & Quilty PG 1973 The geology of Western Australia - a review. Journal of the Royal Society of Western Australia 56:5-15.

Main AR 1987 Management of remnants of native vegetation - a review of the problems and the development of an approach with reference to the wheatbelt of Western Australia. In: Nature Conservation: The role of remnants of native vegetation (eds DA Saunders, GW Arnold, AA Burbidge & AJM Hopkins). Surrey Beatty & Sons, Chipping Norton, 1-13.

McArthur WM 1991 Reference Soils of South-western Australia. Department of Agriculture, Perth.

Meney KA & Pate JS 1999 Morphological and anatomical descriptions of Restionaceae and allied families and their distribution. In: Australian Rushes - Biology, identification and conservation of Restionaceae and allied families (eds KA Meney & JS Pate). University of Western Australia Press, Perth, 161-461.

Mulcahy MJ 1973 Landforms and soil of southwestern Australia. Journal of the Royal Society of Western Australia 56:16-22.

Robinson C & Keighery G 1997 Vegetation and flora of Scott National Park and adjacent recreation reserves. Western Australian Naturalist 21:213-233.

Saunders DA & Curry PJ 1990 The impact of agriculture and pastoral industries on birds in the southern half of Western Australia: Past, present and future. Proceedings of the Ecological Society of Australia 16:303-321.

Smith RS & Ladd PG 1994 Wet heathlands of the southern Swan Coastal Plain, Western Australia: A phytosociological study. Journal of the Royal Society of Western Australia 77:71-79.

Sneath PHA & Sokal RR 1973 Numerical Taxonomy: The Principles and Practice of Numerical Classification. Freeman, San Francisco.

Tille P & Lantzke N 1990 Busselton - Margaret River - Augusta land capability study; methodology and results. Division of Resource Management Technical Report 109. Volumes 1 & 2. Western Australian Department of Agriculture, Perth.

Appendix 1

Sorted two way table showing species occurrence by community type. Only taxa which occurred in at least two sites were included in the analysis. Columns represent individual sites with * indicating taxon occurrence at that site. Similar sites are classified into community types.

	COMMUNITY TYPE								
	1	2	3	4	5	6	7	8	9
SPECIES GROUP A									
Acacia extensa			*	*					
Darwinia oederoides	*			*					
Philotheca spicata				*	*				
Xanthosia huegelii				*	*				
Austrodanthonia setacea	*			** *					
Thysanotus tenellus	*			***					
Stylidium luteum subsp *glaucifolium*				**					
Caesia micrantha	*	*		* * *				*	
Chamaescilla corymbosa	**			* * *					
Burchardia multiflora	*		*	** *					
Homalosciadium homalocarpum				** * *		*			
Patersonia juncea				* *					
SPECIES GROUP B									
Acacia pulchella	**		*	***					
Aira caryophyllea	**		**	* * **					
Hyalosperma cotula	***			*** ***				*	
Siloxerus humifusus	** *			*** ***					*
Patersonia occidentalis	*		*	*** ***	*			*	*
Podolepis gracilis				**** *					*
Briza minor	***		*	* ** **					**
Desmocladus fasciculatus	***	**	*	* ****					***
Opercularia vaginata	***		**	* **		*		*	**
Xanthorrhoea preissii	*		**	* ****					*
Aphelia cyperoides	****	***	* **	*******	*	*		**	*
Centrolepis aristata	****	**	****	* *****			*	*	*
Philydrella pygmaea	** *	**	* **	*** * *				**	*
Lepidosperma squamatum	*	*	****	*** * *		*		**	
Schoenus odontocarpus	* *		***	** * *			*		
Kunzea aff *micrantha* (BJK&NG 40)	***	**	****	*				*	
Drosera glanduligera	* **		* *	*** *					
Hemiandra pungens	***		* *	** **		*			
Hypochaeris glabra	****		****	****	*	*			
Phyllangium paradoxum	* *		***	****	*	*		*	
Cyperus tenellus	** *	*		***			*	****	
Lepyrodia aff *macra* (BJK&NG 1026)	**	*		** * *				*****	
Tremulina tremula	* **		*	** * *				**** *	
Loxocarya magna	***	*	***	*** *				**** *	
Pericalymma ellipticum	* **	***	****	* * *	*			*****	*
Stylidium ecorne	* *			* **			*	* ***	
Thelymitra flexuosa	***			** *				*	
Viminaria juncea	***	*	**	* *		*		*** *	
Drosera macrantha subsp *macrantha*	*		**	* * *					
Stylidium perpusillum	*			* *					
Hakea sp (BJK&NG 226)	*	***	* **	* * **					
Stylidium bulbiferum	**		* *	* * **		*			

Appendix 1 (continued)

	COMMUNITY TYPE								
	1	2	3	4	5	6	7	8	9
SPECIES GROUP C									
Desmocladus flexuosus			*					*	
Goodenia eatoniana	*		* *					*	
Hibbertia hypericoides			* *						
Dryandra nivea subsp *uliginosa*	*	* *	*					*	
Vulpia bromoides		*	*	* *					
Laxmannia sessiliflora subsp *australis*	* * *		* *						
Stylidium repens	* * *		* *	*					
Millotia tenuifolia	*		* *						
Pyrorchis nigricans	*		*						
Levenhookia pusilla	*		* * *	*					
Thelymitra antennifera	*	*	* * * *				*		
SPECIES GROUP D									
Astartea aff *fascicularis*				*				*	
Juncus bufonius		*		* *			*	*	
Cyathochaeta avenacea				* *				*	*
Melaleuca preissiana		*		* *					*
Meeboldina roycei ms				*					*
Melaleuca aff *incana* (NG&ML 593)				*					*
Eriochilus dilatatus	*			* *					
Loliuni rigidum				* *					
Lepidosperma longitudinale				* * *					
Melaleuca polygaloides				* * *					
Poa poiformis				* * *					
Grevillea nuanglesioides		* *	*	* * * * *					*
Stylidium inundatum		*		* * *				*	
Hydrocotyle alata	*	*		* * * * *					
Tribonanthes australis				* * *			*		
SPECIES GROUP E									
Centrolepis glabra				*			*		
Tritluria bibracteata				*			*		
Triglochin centrocarpum				* *			*		
Monopsis debilis	*	*		*			*	*	
Thysanotus multiflorus		*		*					
Hypolaena fastigiata				* *					
Juncus articulatus				* *					
Lotus suaveolens				* * *					
Isolepis cyperoides				* *					
Leucopogon carinatus				* *					
SPECIES GROUP F									
Agonis flexuosa				*		*			
Boronia spathulata		*				*			
Hakea tuberculata				*		*		*	
Kunzea recurva				* *		*	*		
Sowerbaea laxiflora				*		*			
Ornithopus compressus	*		* *			*			
Sonchus oleraceus			*			*			
Parentucellia viscosa			*	* *		*			

Appendix 1 (continued)

	COMMUNITY TYPE								
	1	2	3	4	5	6	7	8	9
SPECIES GROUP G									
Amphipogon debilis				*				*	
Cassytha racemosa				* * *				*	
Isotoma hypocrateriformis				* *					
Bartsia trixago				* *					
Schoenus bifidus				* *					
Stylidium mimeticum	* *	*		* * *					
Thelymitra crinita	*	*		*					
Thysanotus manglesianus	*			*					
Austrostipa compressa			*	* *					
Epilobium billardierianum			*	*					
Trichocline sp (BJK&NG 564)			*	*					
Conostylis setigera			*	*					
Neurachne alopecuroidea			* * *	*					
Selaginella gracillima	*		* *	*					
Pimelea imbricata var *imbricata*			* *						
Schoenus subflavus		*	* *						
Stylidium crassifolium			* *	*					
SPECIES GROUP H									
Acacia myrtifolia				* * *				* * * * * *	
Calothamnus aff *crassus* (R.D.Royce 84)				* * * * *	*			* * * * * *	
Velleia trinervis			*	* * * * * *	*			* * *	
Boronia anceps								* * * * *	
Grevillea aff *manglesioides* (GJK 15158)								* * * * * *	
Stenotalis ramosissima				*				* * * * * *	*
Adenanthos detmoldii								* *	
Chordifex isomorphus				*				* * *	
Melaleuca incana								* * * *	
Caesia occidentalis						*		*	
Mesomelaena tetragona			*	* * *		*		* *	
Vellereophyton dealbatum				* *		*		*	
Stylidium spathulatum				*	*			* *	
Xanthorrhoea platyphylla								* *	
SPECIES GROUP I									
Eutaxia virgata		*		*				*	
Schoenus rigens		*						*	
Hakea ceratophylla								*	*
Schoenus asperocarpus	*							*	
Sphenotoma capitatum					*			*	
Villarsia parnassifolia				*				*	
SPECIES GROUP J									
Actinodium cunninghamii			*		*				
Schoenus curvifolius			*		*				
Cytogonidium leptocarpoides		*			*				
Euchilopsis linearis		*			*				
Dasypogon bromeliifolius		*		*	*			* *	
Darwinia ferricola ms					*			* *	
Cassytha glabella	*		* *	*	*				
Drosera pallida				*	*				

Appendix 1 (continued)

	COMMUNITY TYPE								
	1	2	3	4	5	6	7	8	9
Dampiera linearis	**	**	*	**	*			*	
Baxteria australis				*	*				
Leucopogon pendulus	*			*					
Sphenotoma gracile				* *					
SPECIES GROUP K									
Acacia stenoptera	***	**							
Chamelaucium roycei ms	***	*							
Podolepis gracilis swamp form (GJK 13126)	* *								
Polypogon tenellus	* *								
Conostylis aculeata	**	*		*					
Isolepis oldfieldiana	*	*							
Calothamnus aff *quadrifidus* (BJK&NG 230)	*	*							
Patersonia occidentalis (swamp form)	*							*	
Thysanotus patersonii	*		*						
Briza maxima	***			*	*	*	*		*
Romulea rosea	* *					*	*		
Haloragis tenuifolia	*			*			*		
Villarsia capitata	*						*		
Andersonia ferricola ms	* *		* *						
Drosera neesii	*		*						
Centrolepis drummondiana	**	*	**						
Lotus angustissimus	**		*						
Hypolaena pubescens	**			**				* *	
Microtis media	**			*				* *	
SPECIES GROUP L									
Borya scirpoidea	* **	* *	**						
Drosera rosulata	* **	* *					*		
Caladenia marginata	****	*		**					
Drosera menziesii subsp *menziesii*	* *	***		**					
Isolepis marginata	**	*		*			*		
Polypompholyx multifida	***	***	*	* *			*		
Elythranthera brunonis	*	*		*					
Stylidium obtusatum	*	*							
Drosera gigantea	*	*	**						
Stylidium calcaratum	* *	*	**						
Thysanotus thyrsoideus	*	**	**						
Hakea sulcata	*	*		*				** *	
Isopogon formosus subsp *dasylepis*	*	*							
Stylidium guttatum	*	*						*	
Caustis dioica	* *	***	**						
Chordifex sp		***	*						
Hypolaena exsulca	*	**	*		*				
Leptocarpus tenax	*	**							
Petrophile latericola ms	*	**							
Lyginia barbata		**						*	
Regelia ciliata		**							

Appendix 1 (continued)

	COMMUNITY TYPE								
	1	2	3	4	5	6	7	8	9
SPECIES GROUP M									
Adenanthos meisneri	*		*						
Hakea varia	*		*	*				*	
Stylidium pulchellum	**				*			*	
Chamaescilla corymbosa var *latifolia*			*					* *	
Hibbertia stellaris	*			*				* * *	
Nuytsia floribunda	*							*	
SPECIES GROUP N									
Angianthus preissianus	****								
Aphelia nutans	****								
Lepidosperma sp (BJK&NG 232)	***								
Siloxerus filifolius	* **								
Stylidium emarginatum	**								
Centrolepis alepyroides	* *							*	
Hydrocotyle callicarpa	* *				*				
Stylidium petiolare	* *								
Vulpia myuros	* *							*	
Centrolepis mutica	* **	*		***					
Verticordia plumosa	*	*		**					
Cicendia filiformis	*			*					
Juncus capitatus	* *			* *					
Schoenus discifer	* *	*		*					
Calothamnus lateralis	*	**			*				
Phylloglossum drummondii	* *	*							
Poa annua	*	*							
Dryandra squarrosa subsp *argillacea*	* *	*							
Utricularia violacea	*	*							
Tribonanthes violacea	**	*							
Crassula natans		*					*		